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Technical Report 202

Updated avifauna of Moku'ae'ae Rock Islet 2019

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Key words: Newell's Shearwater (*Puffinus newelli*), Wedge-tailed Shearwater (*Ardenna pacifica*), Bulwer's Petrel (*Pseudobulweria bulweri*), Barn Owl (*Tyto alba*), Moku'ae'ae Rock Islet, seabird monitoring

Place key words: Moku'ae'ae Rock Islet, Kauaʻi

EXECUTIVE SUMMARY

Moku‘ae‘ae Rock Islet, located off the North shore of Kaua‘i is protected as a Hawai‘i State Seabird Sanctuary. In the late 1970s it was also the site of a cross-fostering project for the endangered Newell’s Shearwater *Puffinus newelli*. Few avifauna surveys have been undertaken on the islet, with the most recent prior to this report being undertaken by the Kaua‘i Endangered Seabird Recovery Project (KESRP) in 2013 and 2015 respectively. For this study, the islet was surveyed in June and October of both 2018 and 2019. Burrow searches were conducted across the entire islet to obtain breeding population estimates for each species and to assess whether there was any recent sign of Newell’s Shearwater breeding activity. Two Song Meters (Wildlife Acoustics, SM2+) were also deployed each year at the same two locations, with data collected for two months in June and July. Auditory surveys were also conducted in June 2018 for two hours after sunset and one and a half hours before sunrise. A total of 17 bird species was recorded over the course of the two years, consisting of eight seabird species (of which three – Bulwer’s Petrel *Bulweria bulwerii*, Wedge-tailed Shearwater *Ardenna pacifica* and Red-tailed Tropicbird *Phaethon rubricauda* - were confirmed breeding), one native waterfowl species (Nene *Branta sandvicensis*, which is the first confirmed breeding record on the islet for this species), five migratory species, and three introduced species. As with previous searches of the islet, there was no sign of Newell’s Shearwater breeding activity and only a handful of calls recorded, concurring with previous reports that the cross-fostering project on the islet was not successful. Despite this, the islet remains an important sanctuary for the three seabird species recorded as breeding on the islet during the surveys and remains the only known breeding colony of Bulwer’s Petrel on Kaua‘i. Depredation by the introduced Barn Owl *Tyto alba* was identified as a significant threat to seabirds breeding on the islet. Future management actions are suggested to improve the islet for breeding seabirds.

1.0 INTRODUCTION

Moku‘ae‘ae Rock Islet is a small (1.3ha) islet located at 22º14'5" N latitude, 159º24' 11" W longitude. The islet sits 117m off the northern coast of the island of Kaua‘i (Figure 1) in the Main Hawaiian Islands and directly off of Kīlauea Point National Wildlife Refuge (KPNWR). At its highest point, it is 31.7m above sea level and consists of a gently sloping plateau surrounded on all sides by cliffs and rock scree leading down to tide pools and a rocky intertidal zone (Figure 2). The majority of vegetation on the islet is native, dominated by *Sesuvium portulacastrum*, *Chenopodium oahuense, Boerhavia coccinea* and *Portulaca lutea* (Eijzenga and Preston 2008). The islet is protected as a Hawai‘i State Seabird Sanctuary, with access prohibited above the high-water mark without a permit and is one of only two islets associated with Kaua‘i. It is considered a priority islet by the Offshore Islet Restoration Committee (Swenson 2008), a multi-agency group focused on restoring native bird and plant communities on islets across the main Hawaiian island chain. Apart from the visits outlined in this report, the islet is rarely visited by biologists.

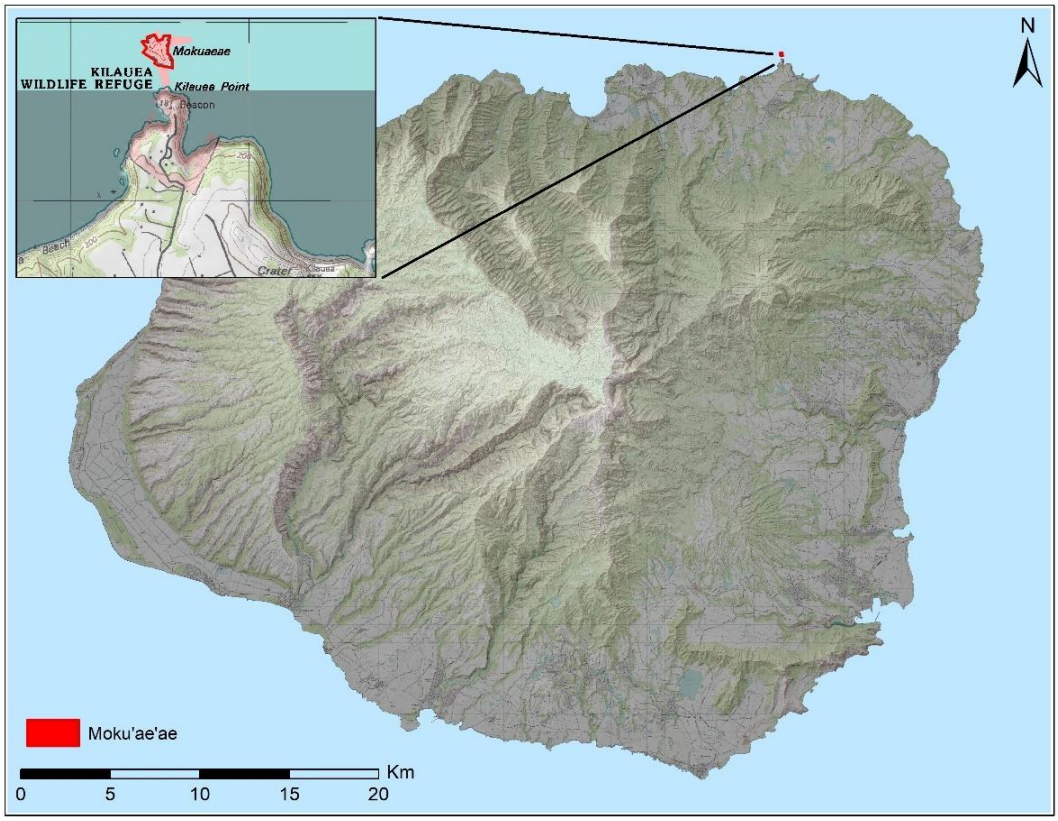

Figure 1. Map showing location of Moku’ae’ae Rock Islet in relation to Kauaʻi.

Figure 2. Moku’ae’ae Rock Islet, as seen from above and to the east.

From a seabird point of view the islet is of particular interest as it was one of two locations used for a Newell's Shearwater *Puffinus newelli* cross-fostering experiment that took place between 1978 and 1980 (Byrd et al. 1984). Over those years, a total of 90 Newell's Shearwater eggs were removed from burrows in montane colonies and placed in Wedge-tailed Shearwater *Ardenna pacifica* burrows on Moku'ae'ae (25 eggs in 1979 only) and the adjacent Kīlauea Point National Wildlife Refuge (65 eggs in total over three year period). Of the 25 eggs moved to Moku'ae'ae, 13 fledged with 44% depredated by the introduced Common Myna *Acridotheres tristis*. It was hoped that of the birds that fledged, the survivors would return to breed on Moku'ae'ae in the future. A small number of surveys have been conducted on Moku'ae'ae since the cross-fostering project ended, with the most recent being surveys conducted by the Kaua'i Endangered Seabird Recovery Project (KESRP) in 2013 and 2015 (Raine et al. 2017b).

We undertook surveys in 2018 and 2019 with four main purposes; (i) to provide an updated inventory of all seabird species presently breeding on the islet, including estimated breeding population sizes, (ii) compare these estimated population sizes with data collected by KESRP in 2013 and 2015, (iii) assess whether or not there was evidence that Newell's Shearwaters were breeding on the islet, thus evaluating the success of the cross-fostering project and (iv) create rough reproductive success rate estimates for the most common seabird species breeding on Moku'ae'ae – the Wedge-tailed Shearwater.

2.0 METHODOLOGY

2.1 Burrow searching

Moku'ae'ae was visited by a team of ornithologists from KESRP[1] twice in 2018 (4-5th June and 31st October) and twice in 2019 (June 12th and October 25th). Due to its small size, it was possible to search the entire islet for burrows (e.g. Figures 3 & 4), with the exception of a few sheer cliff areas (and as such population estimates provided in this report must be considered as minimum estimates as some areas were not searched). On all occasions the islet was searched systematically starting with the perimeter and then moving to the upper plateau, which was quartered along cardinal directions (using ropes to prevent double counting) and searched extensively as well. A total of 50 artificial burrows consisting of concrete tubes are also located on the islet (mainly on the upper plateau); these were installed as part of the aforementioned Newell's Shearwater cross-fostering project. All of these were also inspected during both surveys in 2019 and their contents recorded.

Bulwer's Petrel typically nest in narrow crevices and rock piles which can be very hard to comprehensively search and they typically show relatively little to no sign outside their burrows. This means that standard visual searches in this kind of habitat significantly under-estimate counts of this species. To compensate for this issue, surveyors also replicated the soft barking call of this species whenever entering a new area on the islet that they were searching. Bulwer's Petrels are very responsive to this technique, and the majority of burrows found on Moku'ae'ae Islet of this species were located through this additional search method.

[1] and on one occasion accompanied by a biologist from the Department of Forestry & Wildlife (DOFAW)

As with the surveys conducted by KESRP in 2013 and 2015, the locations of all burrows were recorded using an iPad Mini 3. All burrows within the area were counted, their status noted, and a GPS point taken. For burrows located, the following data were collected: (i) adult(s) present, (ii) chick present, (iii) egg present, (iv) eggshell present, (v) guano present, (vi) seabird footprints present, (vii) nest material present, (viii) digging evident. If a chick was present, it was also listed as either an SDC (small downy chick), LDC (large downy chick), MFC (medium-feathered chick) or FFC (fully-feathered chick). In the case of burrows where the burrow was too deep to see the burrow chamber, this was noted and data was still collected on any seabird sign found around the burrow entrance.

Minimum breeding population estimates for all species on the islet were then created. Surveys in June were used to create population estimates for Bulwer's Petrel *Bulweria bulwerii* and Red-tailed Tropicbird *Phaethon rubricauda* as this is during the peak breeding period on Kauaʻi for these two species (Harrison 1990, KESRP unpub data). The total number of confirmed breeding pairs recorded on the islet during these surveys was used for this minimum estimate, where 'confirmed breeding' was defined as burrows where the presence of an incubating adult, chick or egg was confirmed. For Wedge-tailed Shearwaters, the results of both June and October surveys were used to create population estimates. In this case, the minimum estimate was created from the number of incubating adults recorded during the June survey and the maximum from the total number of apparently active burrows recorded in either June or October, whatever was highest. Apparently active burrows included all burrows where there was sign that shearwaters had been using the burrow that season, even if it was empty. This included clear footprints, guano, nest material, eggshell etc. As the methods used in 2018 and 2019 were the same as those used by KESRP in 2013 and 2015, the results are directly comparable.

2.2 Auditory Surveys

Auditory surveys were also carried out on the 4th June 2018, for two hours after sunset, and the 5th June 2018 for 1.5 hours starting two hours before sunrise using night vision equipment (night vision goggles US Night Vision PVS-7 Gen 3). These were undertaken specifically to further assess the presence of Newell's Shearwater, and were undertaken at five locations on the islet. Locations were chosen such that they gave surveyors the maximum auditory survey coverage across the islet, and were the same locations used by KESRP surveyors during the May 2013 trip.

Surveys were split into 30-minute sessions, with 5 minutes allotted for the collection of weather data, 25 minutes for auditory surveying, and 5-10 minutes for concurrent night vision. Surveyors recorded all Newell's Shearwater calls (classified as a single unbroken note or series of notes) heard during the survey period as well as any visual observations made during each survey period (either by eye or through night-vision equipment). For any observation of the species, data were collected on time of observation, species, direction from observer, distance from observer and the behavior of the bird (with particular attention paid to circling behavior and ground-calling). Data were also collected on any Bulwer's Petrel and Barn Owl that were recorded during the surveys. Data were recorded on an iPad Mini 3 using a specially designed app.

Figure 3. Team surveying on the north-west side of Moku'ae'ae Rock Islet in June 2018.

Figure 4. Team surveying on the south-east side of Moku'ae'ae Rock Islet in October 2018.

2.3 Acoustic monitoring

Two acoustic sensors (Song Meter 2+ sensors (http://www.wildlifeacoustics.com)) were deployed on Moku'ae'ae to monitor Newell's Shearwater (2018 only), Bulwer's Petrel (2018 and 2019), Wedge-tailed Shearwater (2018 and 2019) and Barn Owl (2018 and 2019) vocal activity. The same locations were chosen in both years (Figure 3). In 2018, song meters were deployed on 4 June and recovered on 25 August, while in 2019 song meters were deployed on 11 June and recovered on 22 October. Song Meters were powered by 4 D-cell alkaline batteries and stored recordings on two 32 GB SD memory cards. All sensors were fitted with two omni-directional microphones which had Scotch Guard water repellent applied to them to improve water proofing. Microphones were arrayed horizontal to the ground and one on each unit had an additional rain shield installed over it. Sensors were programmed to record 1 minute every 5 minutes for 3 hours after sunset, and 1 minute every 10 minutes for three hours before sunrise. Programming was undertaken using the SMCONFIG software package (reference or source?).

2.3.1 Acoustic Analysis

Automated analysis of all field recordings was carried out by Conservation Metrics (CMI). Field recordings were split into 2-second clips and measurements of 10 spectro-temporal features typically found in animal sounds extracted. A deep neural network (DNN) classification model was then applied to the data, returning a probability that each given 2-second window contained a sound produced by each target species.

The data from Moku'ae'ae were processed using a multi-species DNN model (Hawaii_Multi_07Jun18 _V21) developed by CMI in 2018. This model was trained to detect each species of interest using training and cross-validation datasets containing examples of positive sounds (vocalizations from target species) and representative examples of negative sounds from the soundscape at a range of survey sites on Kaua'i and throughout Hawai'i and other Pacific Islands. The DNN learns which spectro-temporal features best differentiate target sounds from other sounds in the environment, and the resultant model can then be applied to raw acoustic data. This DNN model predicted the presence of 21 signals common in Hawaiian soundscapes simultaneously. These included survey target species such as Bulwer's Petrel, and Barn Owl; as well as common non-target sounds like Japanese Bush-warbler *Horornis diphone*, roosters *Gallus gallus domesticus*, and Common Coquí frog *Eleutherodactylus coqui*. The multiclass framework enabled the model to better differentiate target species from each other, and from other background sounds. Bayesian methods were then used to quantify Wedge-tailed Shearwater activity while a traditional frequentist approach was used to quantify Newell's Shearwater, Bulwer's Petrel, and Barn Owl activity. Both methods are outlined below.

For species analyzed with the traditional frequentist methodology all acoustic events above a threshold DNN classification score were manually reviewed to eliminate false positives (Type I error) from results (i.e. data with the highest DNN confidence of containing the target species were reviewed to confirm or reject model predictions). Specific DNN classification thresholds vary across species, model versions, and survey objectives. To assess model performance, and select classification thresholds, a test dataset was created containing a known number of positives for each class. This test dataset was then used to

determine the classification score that achieved the best balance between detecting rare calls and calculating acoustic activity indices that were sufficient to detect yearly trends, differences among sites, and seasonal patterns; while maintaining an acceptably low rate of false positives to minimize the effort required to manually review results. The results of the traditional analysis approach comprise the number of confirmed species detections, above the selected classification threshold, occurring in each minute of acoustic data. Traditional call rate estimates were then calculated by dividing the total number of detected 2-second clips containing target species calls by the total minutes of recording effort (0-30 calls per minute), in a given unit of time.

Wedge-tailed Shearwater was the only species analyzed using a Bayesian approach. This approach partitioned variance into multiple sources of stochasticity that influence variables contributing to an outcome—in this case, seabird behavior and/or acoustic detection probabilities. Most importantly, Bayesian statistics disentangle process error (real-world differences in mean call rates and abundance) from observer error (variation in measured call rates at any given point in time and space). By incorporating multiple potential sources of variation, the Bayesian approach generates better estimates of the true underlying call rates at each site than traditional frequentist methods alone.

The Bayesian model leveraged both types of data generated by the analysis process—DNN scores and reviewed samples—in a probabilistic framework by estimating a functional relationship between DNN score of an event and true probability of that event being a Wedge-tailed Shearwater call. It also allowed for the effects of additional covariates including stage of the breeding season, moon illumination, time of day, four metrics of microphone quality and detection probability, and the sum of the DNN model scores predicted for other signal types in the multiclass model. The Bayesian model was implemented using standard MCMC fitting methods (Plummer 2003), the R programming language, and JAGS ("Just Another Gibbs Sampler") (Plummer 2003).

The call rate estimates were sampled from the Bayesian posterior distributions and are represented in this report by box plots that indicate the mean estimated call rate, 25% and 75% quantiles, and 95% credible interval (equivalent to the 2.5% and 97.5% quantiles). Statistical difference between any call rate estimates were then discerned when 25% and 75% quantiles of one rate did not overlap with 25% and 75% quantiles of another.

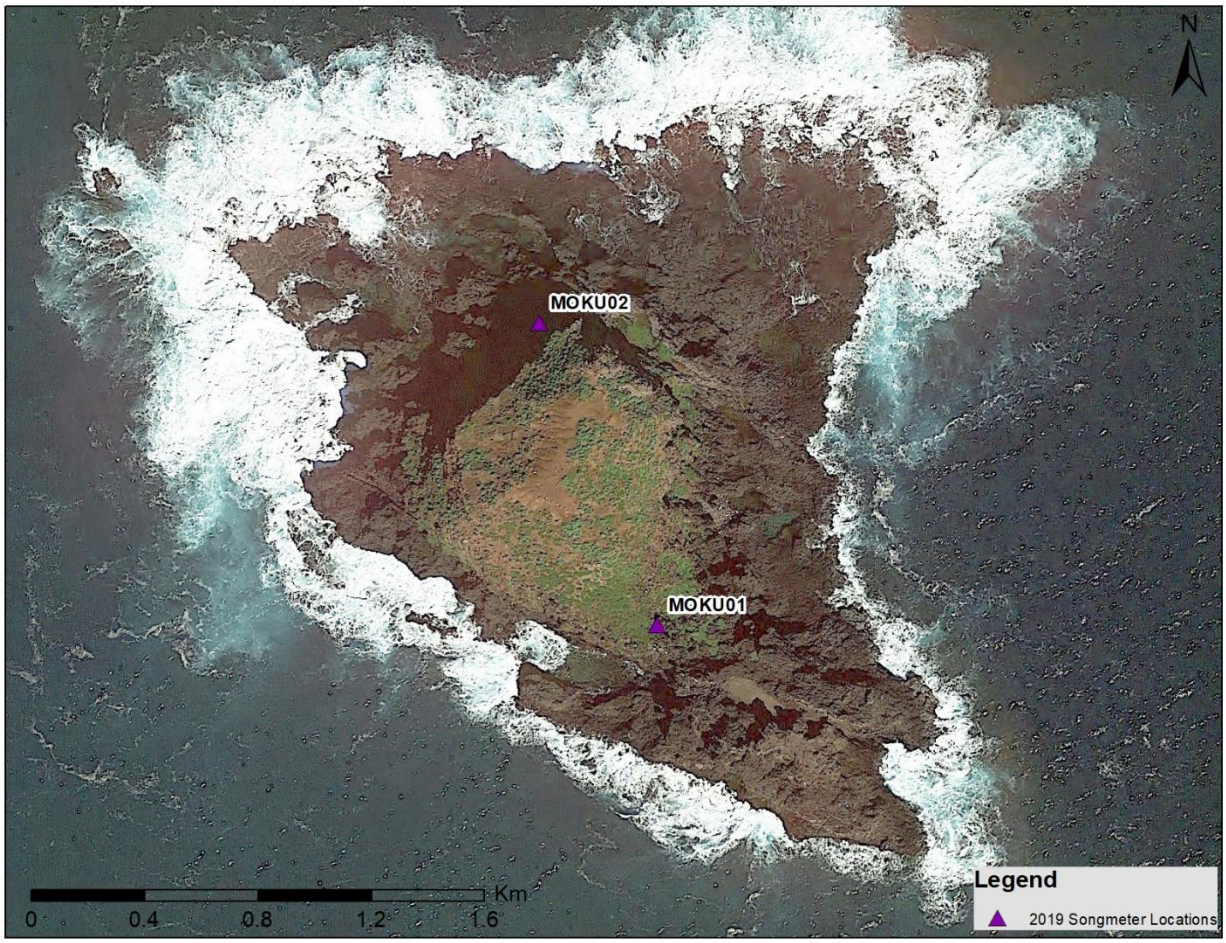

Figure 5. Survey locations on Moku'ae'ae Rock Islet in 2018 and 2019 (the same sites were used in both years).

3.0 RESULTS

A total of 17 bird species was recorded over the course of the two years, consisting of eight seabird species (of which three – Bulwer's Petrel, Wedge-tailed Shearwater and Red-tailed Tropicbird - were confirmed breeding), one native waterfowl species (Nene *Branta sandvicensis*, which was the first confirmed breeding record for this species on the islet), five migratory species, and three introduced species.

A summary of population estimates for breeding seabirds on Moku'ae'ae Rock Islet in 2018 and 2019 is presented in Table 1, and compared with results from the KESRP surveys in 2013 and 2015 as well as an earlier survey conducted in 2007 (Eijzenga and Preston 2008). Individual species accounts of all seabird species recorded during surveys follows.

	Year (Month)				
Species	**2007 (Sept)**	**2013 (May)**	**2015 (Sept)**	**2018 (Jun&Oct)**	**2019 (Jun & Oct)**
Wedge-tailed Shearwater	91 nests	119-695bp	644bp	291-848bp	406-695bp
Bulwer's Petrel	None found*	16-19bp	4bp*	25-27bp	20bp
Red-tailed Tropicbird	2 nests*	22bp	4bp*	39bp	28bp

Table 1. Estimate of breeding pairs of seabird species on Moku'ae'ae Rock Islet in the most recent surveys (2018 and 2019) and three previous surveys: September 2007 (Eijzenga and Preston 2008), May 2013 (Raine et al. 2017b) and September 2015 (Raine et al. 2017b). **Survey undertaken outside of the peak breeding season for this species.*

3.1 BREEDING SEABIRDS

- **Bulwer's Petrel** *Bulweria bulwerii*

Population estimates of breeding pairs (bp) for this species were similar to those found in 2013 (22bp in 2013, 25-27 bp in 2018 and 20 bp in 2019). As with 2013, burrows were located predominantly in boulder fields around the perimeter of the island (Figures 6-8) and in many cases near the intertidal zone. In several boulder fields with high concentrations of burrows, multiple birds were found nesting in close proximity to each other. A total of 17 Barn Owl-depredated Bulwer's Petrels were also found during the four surveys, with 1 in June 2018, 5 in June 2019 1 in October 2018, and 10 in October 2019.

Figure 6. Typical Bulwer's Petrel breeding habitat on Moku'ae'ae Islet.

Figure 7. Adult Bulwer's Petrel incubating in a burrow on Moku'ae'ae Islet in June 2018.

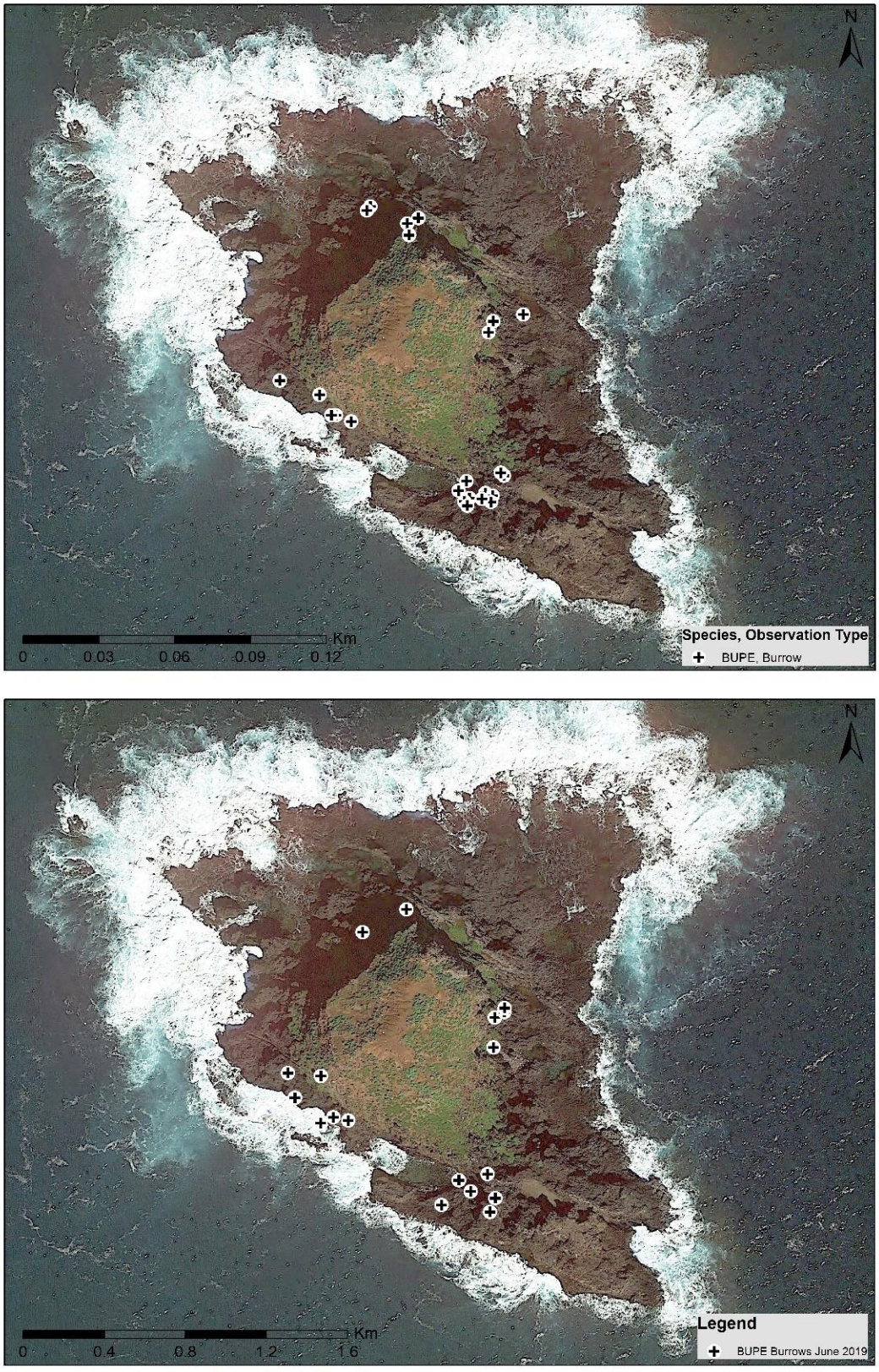

Figure 8 a & b. Distribution of all Bulwer's Petrel burrows recorded on Moku'ae'ae Rock Islet in June 2018 (top) and June 2019 (bottom).

- **Wedge-tailed Shearwater** *Ardenna pacifica*

Population estimates for this species were also similar to those found in 2013 and 2015 (119-695bp in 2013, 644bp in 2015, 291-848bp in 2018 and 406-695bp in 2019). Burrows were found across the islet in all available breeding habitat, with particularly dense concentrations on the sloping sides of the plateau and below the cliffs on the eastern flank (Figures 9 & 10). Data from the most recent surveys (June & October 2019) were considered in more detail (Table 2). In June, of 618 burrows counted, 57.9% had only adults present and a further 11.3% had an egg confirmed. The remainder (30.8%) had signs of activity but no birds or eggs present. In October, only 2 (0.3%) burrows had adults in them, 26.2% had chicks and 73.1% had signs of activity but no birds present. Of the 182 burrows with chicks present, 81.3% had fully feathered chicks and 18.7% medium feathered chicks (see Figures 10a&b for photographs of these stages of chicks).

Wedge-tailed Shearwaters were the only species found using the artificial nests on the upper plateau of the islet. Considering the most recent surveys (2019) only, 77.2% had Wedge-tailed Shearwaters in them in June and 25.0% had chicks in them in October. Due to heavy erosion at these artificial nest sites, most of the tubes are now situated on a steep angle with the result that in many cases the eggs that were laid in them simply rolled out and were found abandoned outside the burrow entrances or further down slope.

A total of 4 Barn Owl-depredated Wedge-tailed Shearwaters were also found during the four surveys, with 2 in June 2018, 1 in June 2019, and 1 in October 2019.

Content	June	October
Total	618	695
Adults only	57.9%	0.3%
MFC	0.0%	4.9%
FFC	0.0%	21.3%
Egg	11.3%	0.4%
Active, empty	30.8%	73.1%

Table 2. Contents of Wedge-tailed Shearwater burrows found on Moku'ae'ae Rock Islet during 2019 surveys. MFC= 'medium feathered chick,' FFC= 'fully feathered chick.'

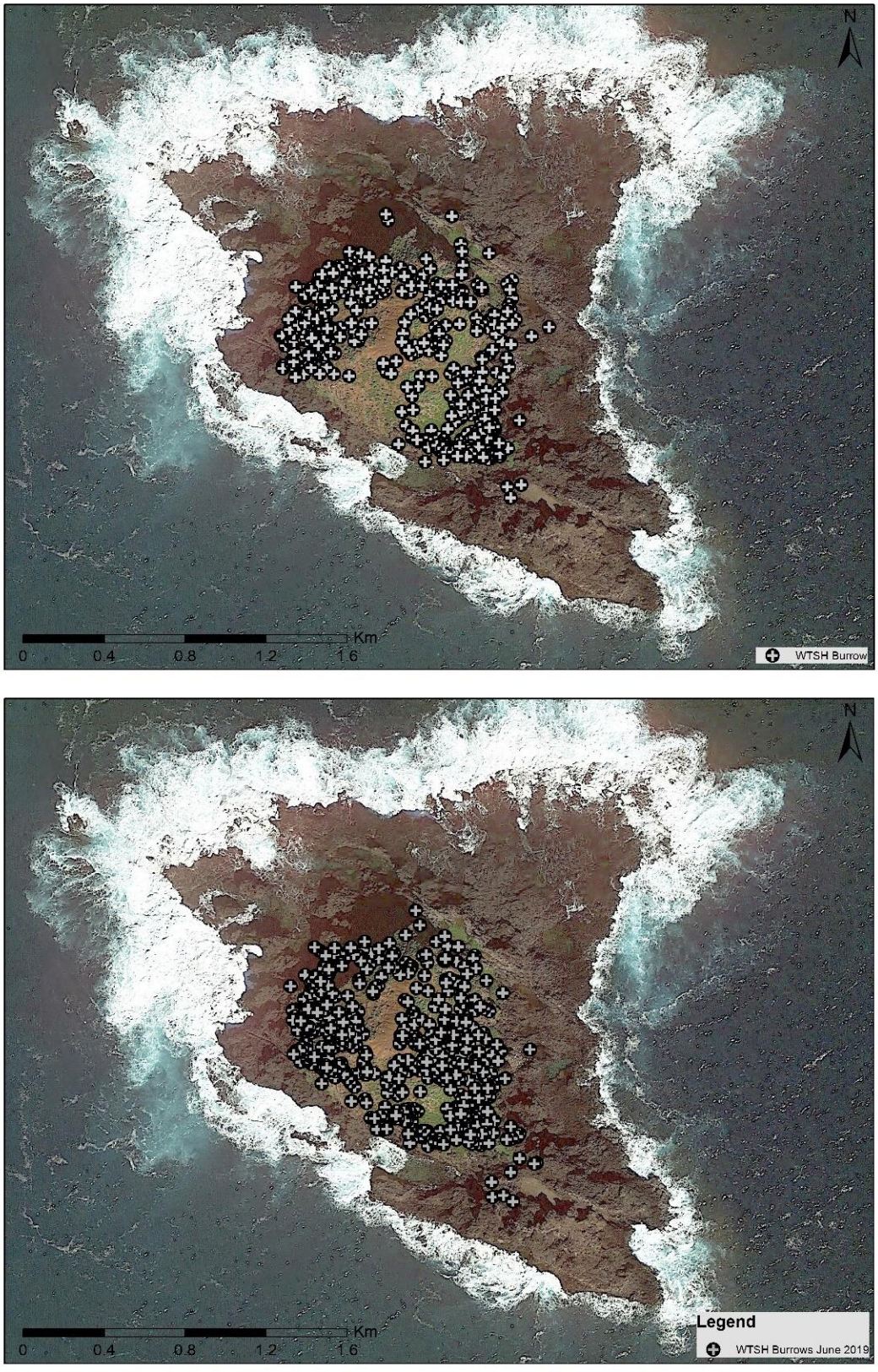

Figure 9 a & b. Distribution of all Wedge-tailed Shearwater burrows recorded on Moku'ae'ae Rock Islet in October 2018 (top) and October 2019 (bottom).

Figure 10 a & b. Wedge-tailed Shearwater chicks were of varying ages during the October surveys, including medium feathered chicks (MFC, top photo) and fully feathered chicks (FFC, bottom photo).

- **Red-tailed Tropicbird** *Phaethon rubricauda*

Population estimates for this species were also relatively similar with the highest count (29bp) in 2018 and the lowest count (22bp) in 2013. Nests were predominantly found in the lower plateau to the south-east of the islet, with scattered nests around the plateau (Figures 11 & 12).

Data from the most recent surveys (June & October 2019) were considered in more detail. In June, of 28 burrows counted, 42.9% had adults present, 46.4.0% had chicks and 10.7% had an egg confirmed. In October there were no active tropicbird nests found.

Figure 11. Red-tailed Tropicbird chick during June survey, classified as a SDC (small downy chick).

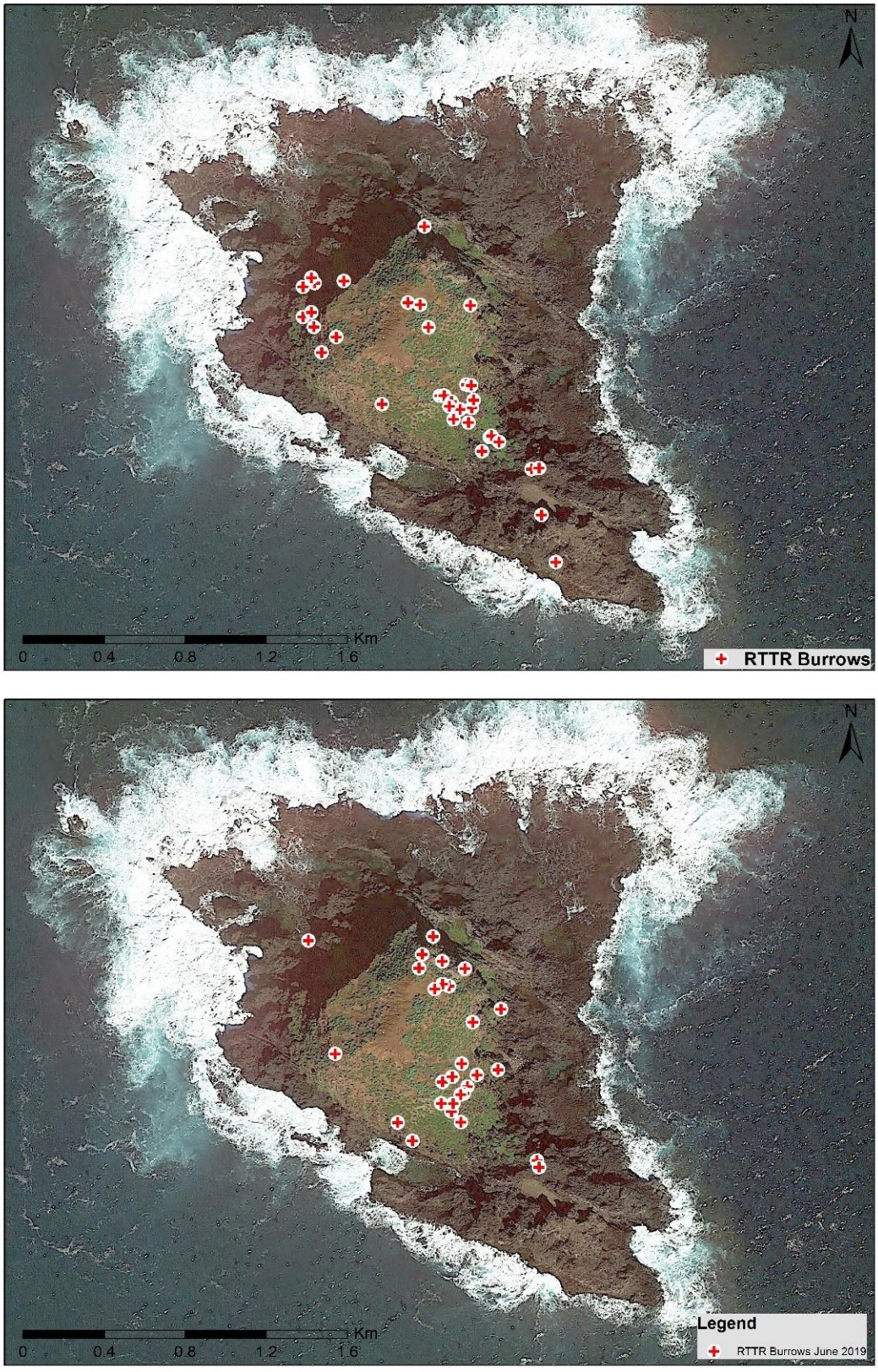

Figure 12 a & b. Distribution of all Red-tailed Tropicbird burrows recorded on Moku'ae'ae Rock Islet in June 2018 (top) and June 2019 (bottom).

3.2 NON-BREEDING SEABIRDS

- **Newell's Shearwater** *Puffinus newelli* **-** No Newell's Shearwaters were physically recorded in either year, either on the islet or passing by. On Kaua'i the breeding season for this species starts in April (with the courtship phase) and birds fledge from late September to early November (Ainley et al. 2019). The peak vocal period for this species is May to mid-September (Raine et al, in prep), so the nocturnal surveys conducted during the June 2018 trip should also have recorded vocalizations of this species if it was present in large numbers. Furthermore, song meters were analyzed for this species throughout the period of deployment in 2018 and only two individual calls were recorded on one Song Meter on one night--presumably a bird flying over on its way to Kīlauea Point NWR. The continued lack of any sign of Newell's Shearwater breeding on the island (no sign was found during surveys in 2013 and 2015 either, Raine et al. 2017b) further suggests that the cross-fostering project on the islet in the late 1970s was unsuccessful – unlike at Kīlauea Point NWR where a small number of Newell's Shearwater continue to breed (Raine et al. 2020b).

- **Great Frigatebird** *Fregata minor* – During all four trips, multiple individuals were seen roosting at the top of the islet. Individuals were also seen during all trips engaging in kleptoparastism of Red-footed Boobies *Sula sula*, Brown Boobies *Sula leucogaster*, Wedge-tailed Shearwaters, and Red-tailed Tropicbirds.

- **Brown Booby** *Sula leucogaster* – One individual was seen roosting on the top of the islet on the night of June 4-5 2018. Moderate numbers of individuals were seen flying past or foraging off the islet on all trips.

- **Red-footed Booby** *Sula sula* – Large numbers of this species were recorded passing by the islet in transit to and from the breeding colony at KPNWR on all trips. The carcass of one bird was found on the islet during the June trip in 2018 and another on the October trip in 2019. The cause of death of each of these birds was unknown.

- **Black Noddy** *Anous minutus* – The remains of a Black Noddy which had been depredated by a Barn Owl were found on the October 2019 trip.

3.3 OTHER BIRD SPECIES ACCOUNTS

- **Nene** *Branta sandvicensis* – Two banded individuals were seen at the top of the islet on the October 2018 trip and the presence of Nene droppings at various locations around the island suggest this was a regular occurrence. An abandoned Nene egg was collected during the October 2018 trip; this was the first confirmed breeding attempt by this species on the islet. During the October 2019 trip a bird (right leg, blue band with white numbers 899) approached surveyors whilst conducting warning displays. A female was subsequently inadvertently flushed off a nest in the naupaka (*Scaevola taccada*) at the top of the islet (Figure 13). The nest was found to contain four eggs. The team moved away from the nest area and the female returned to the nest shortly thereafter. Due to the team's efforts to minimize further disturbance, it was not possible to ascertain whether the female was banded.

Figure 13. Nene nest found on Moku'ae'ae Islet in October 2019. The nest was located in a patch of naupaka on the top of the islet.

- **Ruddy Turnstone** *Arenaria interpres* – Single individuals were recorded foraging along the shoreline during both October trips. This species is a winter visitor to Kauai.

- **Wandering Tattler** *Tringa incana* – Up to 3 individuals were recorded foraging along the shoreline during both October trips. This species is a winter visitor to Kauai.

- **Pacific Golden-Plover** *Pluvialis fulva* - Two carcasses were found on the 4th of June 2018 with signs that they had been depredated by a Barn Owl. One fresh carcass was found on the October 2019 trip with signs that they had been depredated by a Barn Owl.

- **Barn Owl** *Tyto alba* – No Barn Owls were recorded during any trip to the islet. However, depredations of large numbers of Bulwer's Petrel as well as Wedge-tailed Shearwaters, Pacific Golden-Plovers, and Black Noddy were recorded during survey trips, indicating that, as with previous years, Barn Owls continue to be a serious conservation issue on the islet (Figure 14 & 15). This species is a significant introduced predator of seabirds on Kaua'i as well as Lehua Islet (Raine et al. 2019, 2020a).

Figure 14. Remains of two Bulwer's Petrel, depredated by a Barn Owl, lying next to a Barn Owl pellet.

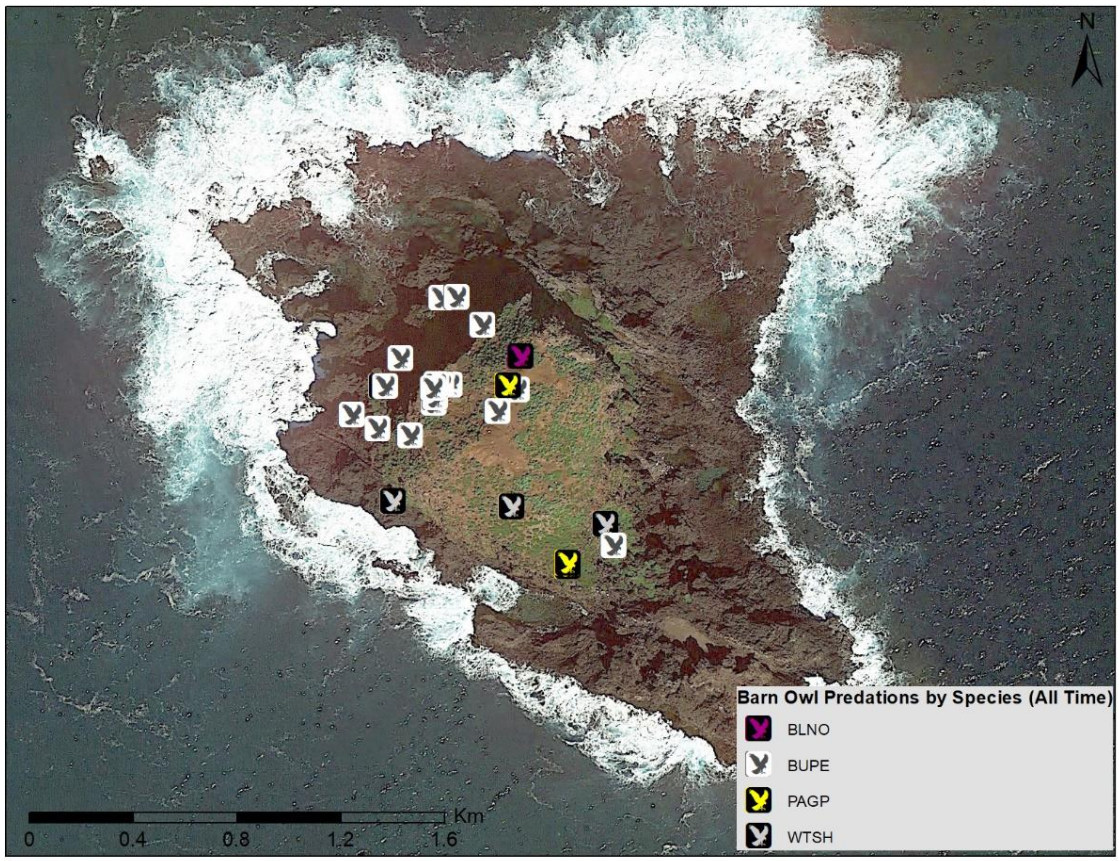

Figure 15. Location of all Barn Owl depredations recorded on Moku'ae'ae Islet during the four survey trips in 2018 and 2019.

- **Osprey** *Pandion haliaetus* – A single individual was seen flying off the eastern side of the islet transiting southeast towards Makapili Rock during the October 2018 trip. This species is a winter visitor to Kauai.

- **Feral pigeon** *Columba livia domestica* – Up to eight birds were recorded on Moku'ae'ae Rock Islet in both 2018 and 2019. It seems likely that this species is breeding on the islet, in the cliff wall on the west side. Several birds were flushed from rock crevices in this area. This species can be a nest competitor for other cliff-nesting species such as tropicbirds (Dobson and Madeiros 2009).

- **Snow Goose** *Chen caerulescens* – An adult Snow Goose was recorded during the June 2018 trip. This species is a vagrant to Kauai.

- **White-rumped Shama** *Copsychus malabaricus* **–** The depredated remains of a White-rumped Shama were recorded during the October 2019 trip. It was not clear what the predator was, but the fact that the remains were scattered over the top of vegetation suggested an avian predator, possibly a Barn Owl. This species is an introduced species on Kauai.

3.4 MAMMALS

- **Black rat** *Rattus rattus* – Surveyors were vigilant at all times for any signs of rat activity on the islet. There were no sightings of live rats, and no signs of rat depredation of either eggs, chicks or adult seabirds. However, the skull of a black rat was discovered on the islet on the October 2019 trip (Figure 16). It was found in an area where Barn Owl depredations are common, so it is possible that the skull was part of a desiccated owl pellet instead of the carcass of a rat that died on the islet. This discovery is, however, of concern as up until this trip there has not been a confirmed record of rats on Moku'ae'ae Islet.

Figure 16. Black rat skull found on Moku'ae'ae Rock Islet in October 2019.

3.5 Acoustic Monitoring

In 2018, a total of 253.47 hours of audio recordings were collected over the course of 166 sensor-nights. In 2019, 400.62 hours of audio recordings were collected over the course of 268 sensor-nights.

Newell's Shearwater

Acoustic data were analyzed for this species in 2018 only. There were 2 Newell's Shearwater calls detected on Moku'ae'ae in 2018, and both occurred at MOKU02 on 10 July at 22:05 suggesting they were both the same bird.

Wedge-tailed Shearwater

Wedge-tailed Shearwater activity was detected at both Moku'ae'ae Song Meters in 2018 and 2019. Daily activity patterns (analyzed in 2018 only) showed low levels throughout the night, followed by a strong peak in activity before sunrise (Figure 17). A peak hour of 120 to 60 minutes before sunrise was therefore used to compare activity among sites.

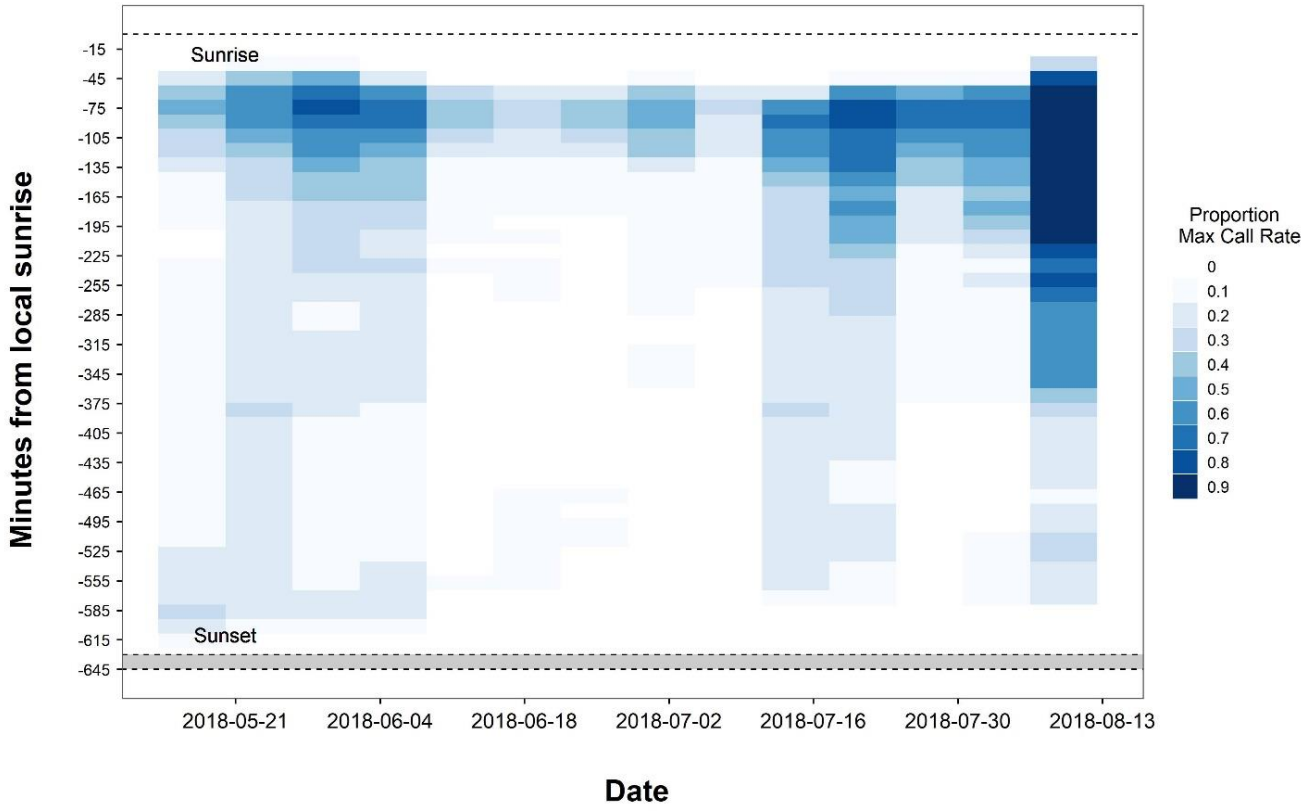

Figure 17. Temporal (seasonal and nightly) Wedge-tailed Shearwater activity patterns estimated for both sites on Moku'ae'ae in the 2018 season. Wedge-tailed Shearwater activity was highest between 120 and 60 minutes before sunrise.

The site with the highest Wedge-tailed Shearwater call rate estimate (Figure 18) in both years was MOKU01 (10.09 calls min-1 ± 0.73 sd in 2018 and 15.76 calls mins-1 +/- 0.78 SD in 2019). Call rates for Wedge-tailed Shearwater were significantly higher for both song meters in 2019 when compared with 2018 (Figure 18).

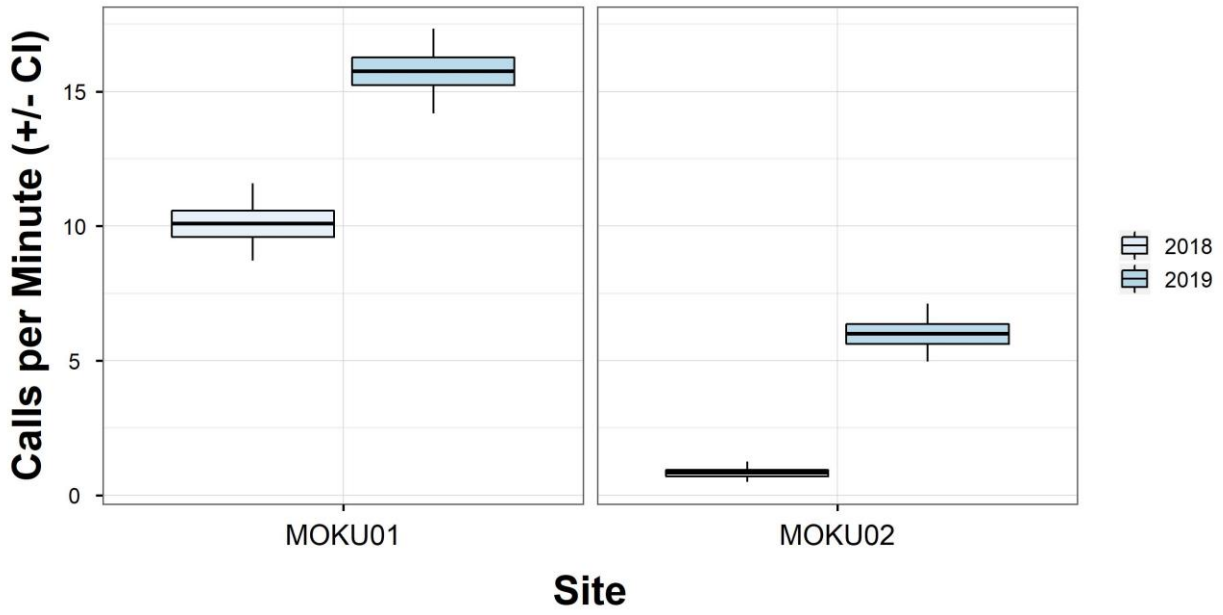

Figure 18. Mean Wedge-tailed Shearwater activity on Moku'ae'ae by site and year during peak calling hour and seasonal comparison period.

Barn Owl

In 2018 there was one Barn Owl call detected on Moku'ae'ae, occurring at MOKU02 on 19 June at 20:53. In 2019 there were three calls detected of this species, again occurring at MOKU02 on 3rd and 4th July respectively.

Bulwer's Petrel

In both years, Bulwer's Petrel vocalizations were only detected at one site on Moku'ae'ae (MOKU02). Daily activity patterns (analysed in 2018 only) showed call rates increasing rapidly from 40 mins after sunset and tapering off an hour before dawn (Figure 19). Bulwer's Petrel calls were also recorded in 2018 throughout June and July but declined markedly in August (Figure 20). A peak period of 40 to 160 minutes after sunset was used to compare activity among sites. MOKU02 had a call rate of 2.22 calls min^{-1} ± 3.64 sd (Figure 20). Call rates were drastically lower in 2019 at the same unit; with the call rate during the nightly peak activity period being 0.01 calls mins-1+/- 0.06 SD (Figure 21).

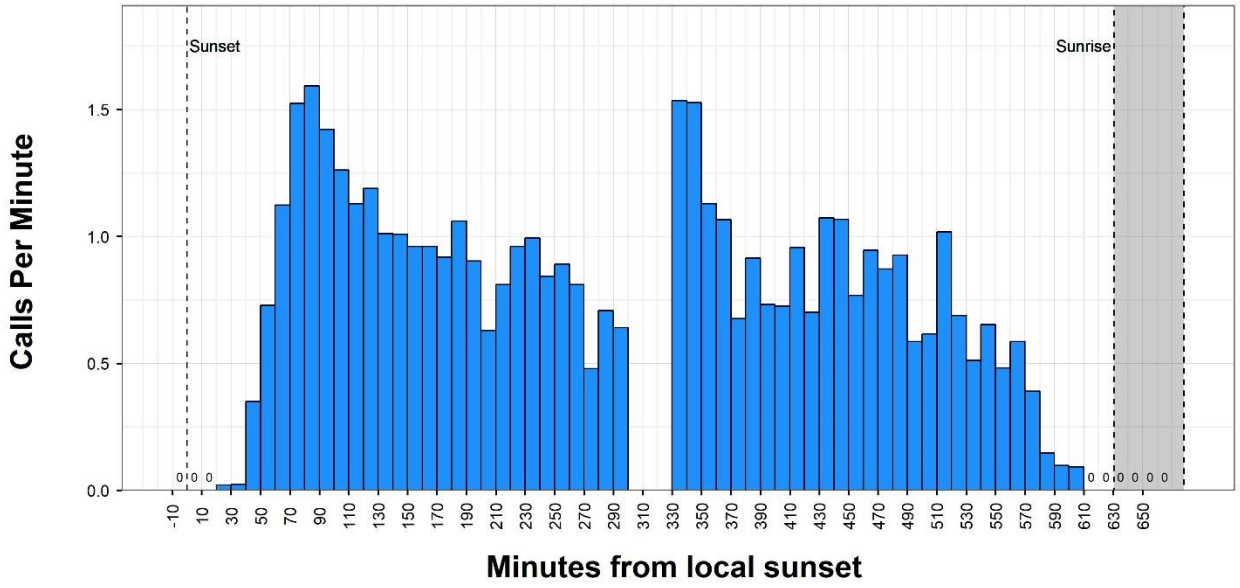

Figure 19. Bulwer's Petrel activity as a function of time from sunset for each site on Moku'ae'ae in 2018.

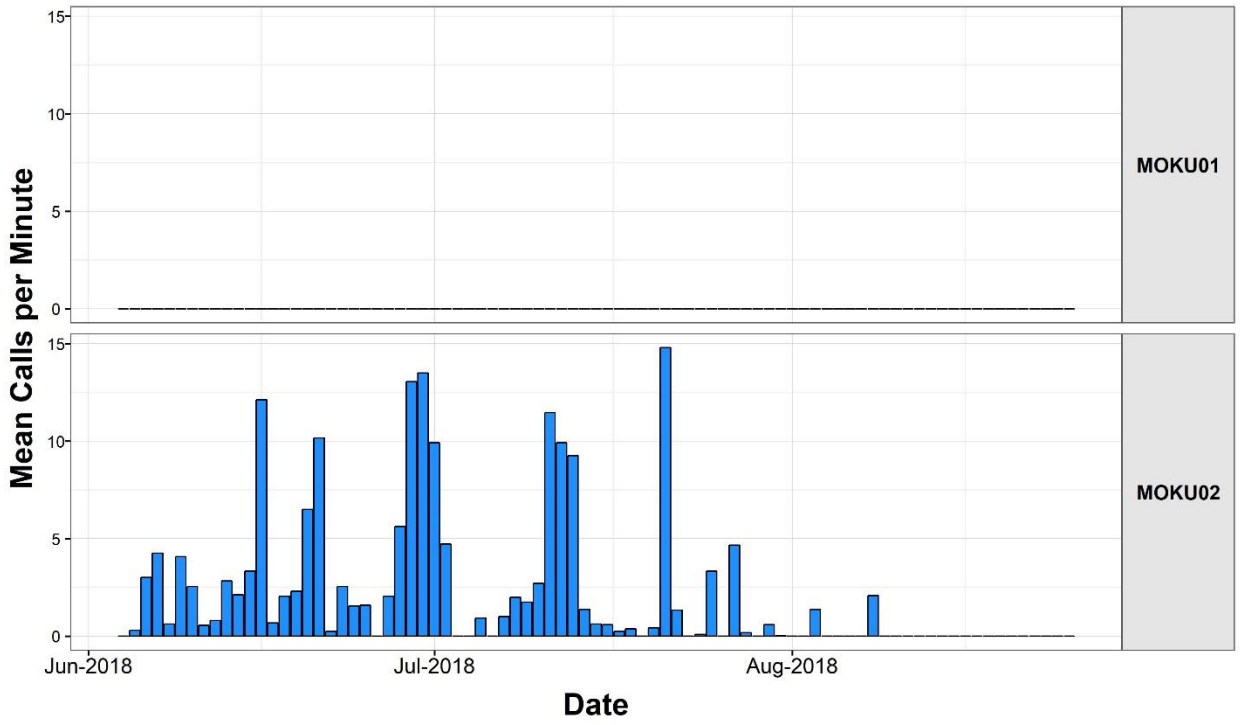

Figure 20. Daily Bulwer's Petrel activity at Moku'ae'ae sites in 2018 during peak calling period (40 to 160 minutes after sunset). Days with zero calls have a black horizontal line representing that day.

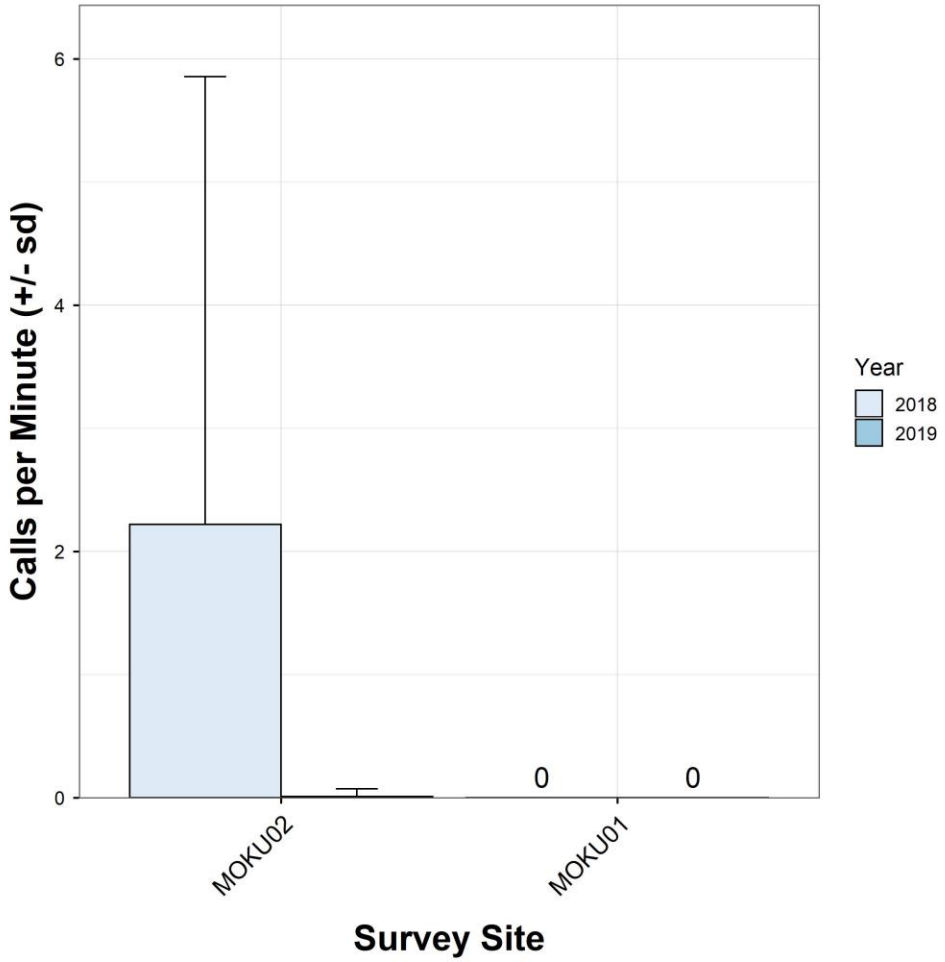

Figure 21. Comparison of Bulwer's Petrel mean acoustic activity rates at Moku'ae'ae sites in 2018 and 2019.

DISCUSSION

While it appears that the attempt to translocate Newell's Shearwater to Moku'ae'ae did not succeed (as no sign of this species has been recorded on any follow-up surveys, and only two calls were recorded across the entire Song Meter recording season in 2018), it is clear that the islet is an important refuge for three seabird species: the Wedge-tailed Shearwater, Red-tailed Tropicbird and Bulwer's Petrel. It remains the only known breeding population of Bulwer's Petrel on Kaua'i and one of only two known breeding populations in the entire County (the other being Lehua Islet).

Considering the serious issues that coastal nesting seabirds face on Kauaʻi itself due to introduced predators (in 2019 alone there were at least 150 Wedge-tailed Shearwaters killed by both cats and dogs in three different colonies on Kauaʻi, Raine pers obs), Moku'ae'ae Islet is an important refuge for all three species. However, it is also clear that birds nesting on the islet are not entirely free of introduced predators. The Barn Owl, introduced to Kauaʻi in 1959 by the Hawaii Department of Agriculture to control rats (Tomich 1962, Au 1966, Au and Swedberg 1966), is a particularly important predator of seabirds and has been recorded killing 11 seabird species across the Hawaiian Islands (Raine et al. 2019). On Moku'ae'ae, Barn Owls target Bulwer's Petrels in particular and this high level of depredation of adult birds is almost certainly suppressing breeding populations of this species on the islet. This could also have been the reason why there were so few calls of Bulwer's Petrel recorded on the Song Meter in 2019 when compared with 2018.

The discovery of a black rat skull in October 2019 is also of concern. It is possible that the skull was deposited on the islet in an owl pellet and had not come from a rat that was present on the islet itself. This seems plausible because it was found in an area with high levels of owl activity. However, this discovery highlights a potential way for rats to get to the islet; an injured rat could escape the talons of an owl and land on the islet, and if it was a pregnant female it could then result in the start of a rat invasion. Furthermore, Moku'ae'ae is only 117m off of Kīlauea Point, and well within swimming range of rats, which are capable of swimming up to 750m (Innes 2005). A critical management action for the islet therefore is to first confirm whether or not rats are present on the islet (using tracking tunnels, chew cards and baited trail cameras) and then either eradicate any rats on the islet if any are found or set up a monitoring and management system to prevent rat incursion.

If the management of introduced predators can be successfully undertaken on the islet (through the removal of owls - which is currently a planned action item by the Division of Forestry & Wildlife - and the prevention of colonization by rats), this would make Moku'ae'ae an even more important refuge for existing seabird populations. Additional management actions could also include the improvement of vegetation on the islet through the removal of introduced plant species (such as *Lantana camara*) and planting of native coastal species – particularly on the heavily denuded top of the islet. This would also help prevent further erosion on the islet, which is a continuing issue on the islet's peak.

Further seabird restoration efforts could be also be considered if introduced predators (particularly Barn Owl) are successfully controlled. Artificial nest boxes could be deployed on the islet to provide more breeding habitat for Bulwer's Petrel which would potentially serve to increase reproductive success rates

for this species and reduce competition with Wedge-tailed Shearwaters which may be an issue. This action would also make it easier to study the species as typical nest sites on the islet are narrow cracks and crevices where it is hard to assess burrow contents and reproductive success rates. Moku'ae'ae might also be a good site to try to create an artificial breeding colony of the endangered Band-rumped Storm-petrel (*Oceanodroma castro*). There are areas on the islet where a small artificial nesting area for this species, coupled with a social attraction system, could be created. This technique has been successfully used in other parts of the species range (Bolton et al. 2004). Band-rumped Storm-petrels are currently known to breed on both the Nā Pali coast and Lehua Islet as well as small scattered pockets in the interior of Kauai (Raine et al. 2017a) and prospecting birds will almost certainly be flying past the islet. Creating a new breeding population of this species on the islet would make it even more important as a Seabird Sanctuary.

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REFERENCES

Ainley, D. G., T. C. Telfer, M. H. Reynolds, and A. F. Raine (2019). Newell's Shearwater (Puffinus newelli), version 2.0. In The Birds of North America. Cornell Lab of Ornithology, Ithaca, NY, USA.

Au, S. (1966). Progress report on the introduction of the Barn Owl in Kauai. 'Elepaio 26:58–60.

Au, S., and G. E. Swedberg (1966). Progress report on the introduction of the Barn Owl (Tyto alba pratincola) to the island of Kauai. 'Elepaio 26:58–60.

Bolton, M., R. Medeiros, B. Hothersall, and A. Campos (2004). The use of artificial breeding chambers as a conservation measure for cavity-nesting procellariiform seabirds: a case study of the Madeiran storm petrel (*Oceanodroma castro*). Biological Conservation 116:73–80.

Byrd, G. V., J. L. Sincock, T. C. Telfer, D. I. Moriarty, and B. G. Brady (1984). A cross-fostering experiment with Newell's race of Manx Shearwater. The Journal of Wildlife Management 48:163.

Dobson, A. L. F., and J. Madeiros (2009). Threats facing Bermuda's breeding seabirds: measures to assist future breeding success. Partners in Flight: Tundra to Tropics. pp. 223–226.

Eijzenga, H., and D. J. Preston (2008). Inventory of seabirds, plants, and arthropods on twenty offshore islets in the main Hawaiian Islands. Bishop Museum Hawai'i Biological Survey 43.

Harrison, C. (1990). Seabirds of Hawaii: natural history and conservation. Cornell University Press, Ithaca, New York.

Innes, J. G. (2005). Ship rat. In The handbook of New Zealand mammals (C. A. King, Editor). 2nd edition. Oxford University Press, Oxford, UK, pp. 187–203.

Plummer, M. (2003). JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20–22. Vienna, Austria.

Raine, A. F., M. Boone, M. McKown, and N. D. Holmes (2017a). The breeding phenology and distribution of the Band-rumped Storm-petrel *Oceanodroma castro* on Kaua'i and Lehua Islet, Hawaiian Islands. Marine Ornithology 45:73–82.

Raine, A. F., S. Driskill, M. Vynne, D. Harvey, and K. Pias (2020a). Managing the Effects of Introduced Predators on Hawaiian Endangered Seabirds. The Journal of Wildlife Management 84:425–435.

Raine, A. F., B. McFarland, M. Boone, and N. Banfield (2017b). An updated avifauna of Moku'ae'ae Rock Islet, Kaua'i. Pacific Science 71:67–76.

Raine, A. F., J. Rothe, S. Rossiter, and S. Driskill (2020b). Monitoring of Newell's Shearwaters at Kīlauea Point National Wildlife Refuge - Annual Report 2019. Kauai Endangered Seabird Recovery Project.

Raine, A. F., M. Vynne, and S. Driskill (2019). The impact of an introduced avian predators, the Barn Owl *Tyto alba*, on Hawaiian seabirds. Marine Ornithology 47:33–38.

Swenson, C. (2008). Offshore Islet Restoration Committee 5-Year Action Plan: 2008 – 2012. OIRC.

Tomich, Q. (1962). Notes on the Barn Owl in Hawaii. ’Elepaio 23:16–17.